MODELLING OF RESIDENTIAL BUILDINGS AND HEATING SYSTEMS

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Summary

The aim of the paper is to illustrate the possibilities offered by model-assisted commissioning in residential buildings. Three examples are considered: two small detached houses and a large multi-storey dwelling building.

A static multi-zone building model is used in each case. A model of the heating system is also used for the multi-storey building.

Both co-heating and tracer gas measurements are used in order to adjust the parameters of each building model.

A complete monitoring of the central heating plant, with measurements of water temperatures and flow rates is used to adjust the parameters of the boiler model.

Keywords: residential building, heating, simulation, audit, energy, control.

INTRODUCTION

In most of the residential buildings, the actual heating demand is badly known. To better identifying it is one of the commissioning challenges.

Co-heating tests and tracer gas methods are of great help in the tuning of a building model.

A more or less detailed monitoring of the heating system can be also helpful.

The results presented hereafter are not new: they were obtained twenty years ago, on two detached houses and on a 33 - dwelling building, built in the sixties. These “old” results are here re-processed as a contribution to the development of model-assisted commissioning methods.

METHODS

Each co-heating test is carried out during one week, with daily temperature set points fixed room by room. In the houses, a night cut-off of all heating sources is performed. Inside and outside microclimates are monitored at the same time as all electric consumption and occupancy heat gains (Figure1).

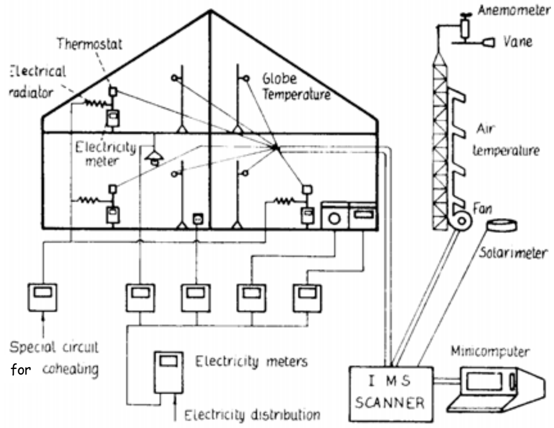

Figure 1: Co-heating experiment [2]

Examples of monitoring results are presented for the kitchen of a wood frame construction bungalow in Figure 2: free heat gain, corresponding inside temperature, heater running time, solar irradiation and outside temperatures are plotted on a two-day period. A severe overheating occurs at the end of each afternoon; it is mostly due to the gas cooker "free" gains. A complete cut off of the system is also observed at noon of day 3: it is due to strong increases of both solar gains and outdoor temperature.

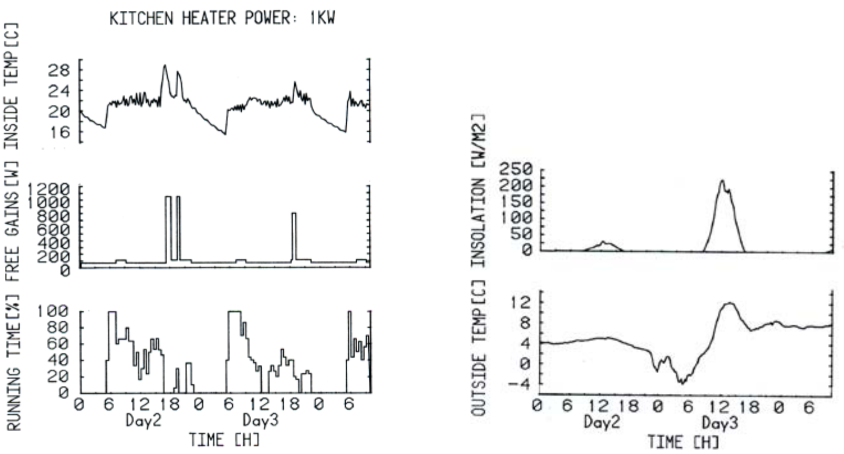

Figure 2: Data recording for the kitchen for a wood frame construction bungalow [2]

Infiltration losses are estimated with help of tracer gas tests.

Time average of all measuring results are used to tune a multizone static building model (Figure 3). Equation 1 gives the heat balance of the static building model.

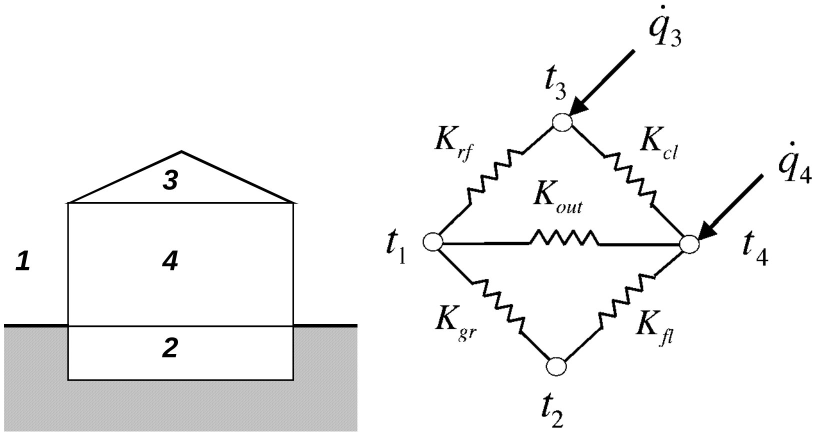

Figure 3: Building multizone static model [1]

$$\begin{bmatrix} 0 \\ \bar{q}_3 \\ \bar{q}_4 \end{bmatrix} + \begin{bmatrix} K_{gr} \\ K_{rf} \\ K_{out} \end{bmatrix} . \bar{t}_1 = \begin{bmatrix} K_{gr} + K_{fl} & 0 & -K_{fl} \\ 0 & K_{rf} + K_{cl} & -K_{cl} \\ -K_{fl} & -K_{cl} & K_{out} + K_{fl} + K_{cl} \end{bmatrix} . \begin{bmatrix} \bar{t}_2 \\ \bar{t}_3 \\ \bar{t}_4 \end{bmatrix} \quad (1)$$

As the temperatures and heat flows are measured, the model allows an adjustment of the transmittances K_{gr} ,$K_{fl,}$,$K_{rf,}$,$K_{cl,}$,$K_{out,}$ corresponding to ground, floor, roof, ceiling, outdoor walls and air renewal, respectively. An iterative procedure is used to reconciliate the calculated global heat loss coefficient, linking the indoor heated zone (node 4) to the outdoor environment (node 1) with its experimental value.

An analysis of the heating plant is also performed, in the case of the dwelling building (Figure 4). In the case considered, the same boiler is supplying both the sanitary hot water and the space heating circuits. Most of the radiators of this building are equipped with thermostatic valves.

The analysis is based here on a classical boiler test (measurements of fuel flow rate and of chimney losses) and on a 21- day monitoring of the whole heating plant: boiler on-off cycling periods, water flow rates and water temperatures of the four water circuits (heating production and distribution, hot water production and distribution) are recorded.

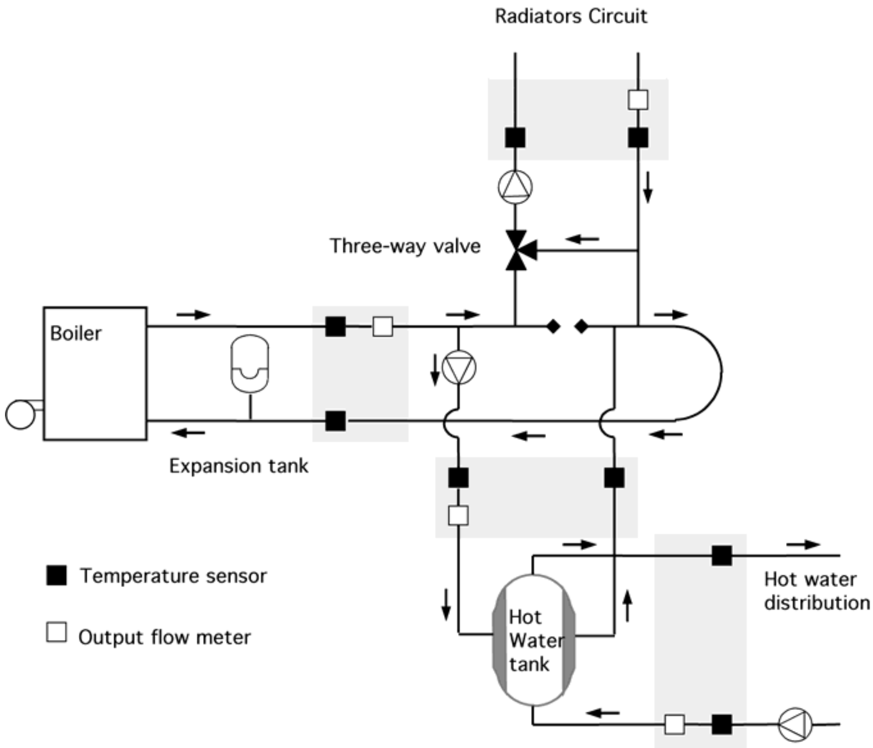

Figure 4: Monitoring of the heating system.

Two boiler models are tested. The first one involves a combustion chamber and two heat exchangers: one for the “useful” gas-water heat exchange and the other one for the heat losses from the water to the environment. The second model is the same, except that it involves also a (fictitious) gas-environment heat exchanger for so-called “hot spots” effects.

This second model is integrated inside the whole heating plant model as shown in Figure 5.

Monitoring results are used to tune the heat transfer coefficients of the three heat exchanger of the boiler model.

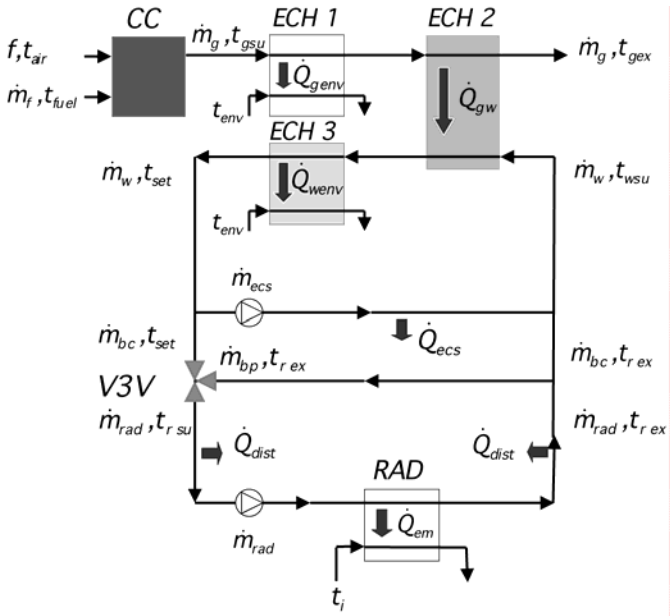

Figure 5: Model of the whole heating plant.

The main equations modelling the boiler, the 3-way mixing valve, the distribution losses, the radiators and the building appears in Figure 6.

A simulation is performed to outline a complete heat balance of the building and of its heating system over a 3 years period (Figure 9).

The radiators valves are here supposed to be “manually” operated. The inputs are the monthly fuel consumptions recorded on 3 years and associated with the corresponding mean outdoor temperatures. The model simulates the interaction between the building and its heating system. The outputs are the resulting indoor temperature (also in monthly average) and the rate of 100% nominal flow supplied radiators.

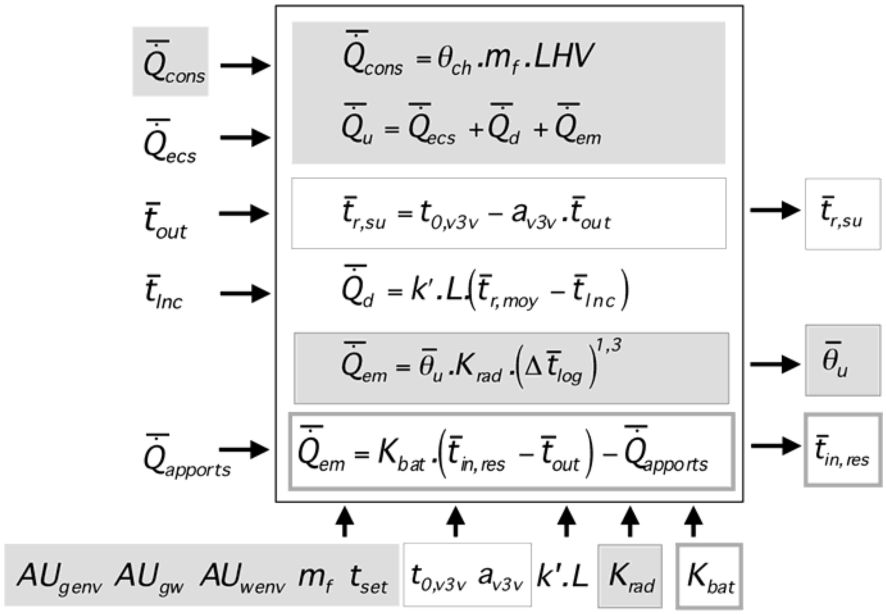

Figure 6: Simulation of heating plant with a central 3-way mixing valve and manually operated radiator valves.

RESULTS

Building analysis results are presented in Figure 7.

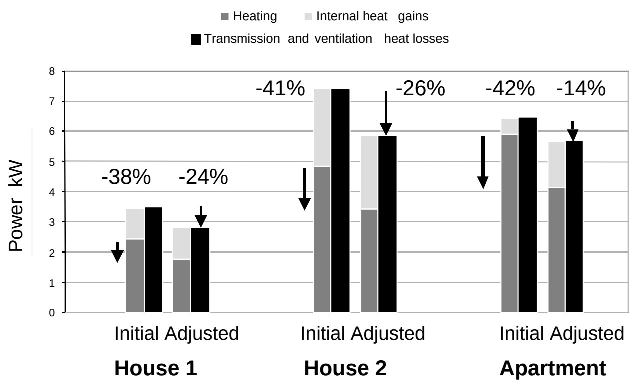

Figure 7: Building analysis results

Transmission and ventilation heat losses (black columns in Figure 7) are initially calculated in theoretical values. They are supposed to be partially compensated by measured internal gains to get an initial estimation of the heat demand. Co-heating tests allows the determination of supplied heat power, leading to a further adjustment of transmission and ventilation heat losses. Measurements reveal a significant overestimation of heat demand, ranging from 38 to 42 %, and an overestimation of heat losses ranging from 14 to 26 %.

In the case of the dwelling building, different models of the boiler, including two or three exchangers, are tested. The coefficients of the models are adjusted on the 21-days monitoring results, and also on a one night test during which the radiators were not supplied at all (in order to bring the boiler in very low part load regime). Those adjustments provides different ranges of values for the model coefficients.

Simulations are then performed for different values of the model coefficients in order to reproduce the measured useful heat power supplied by the boiler for the corresponding measured values of the burner running times and hot water flows. The results are presented in Figure 8.

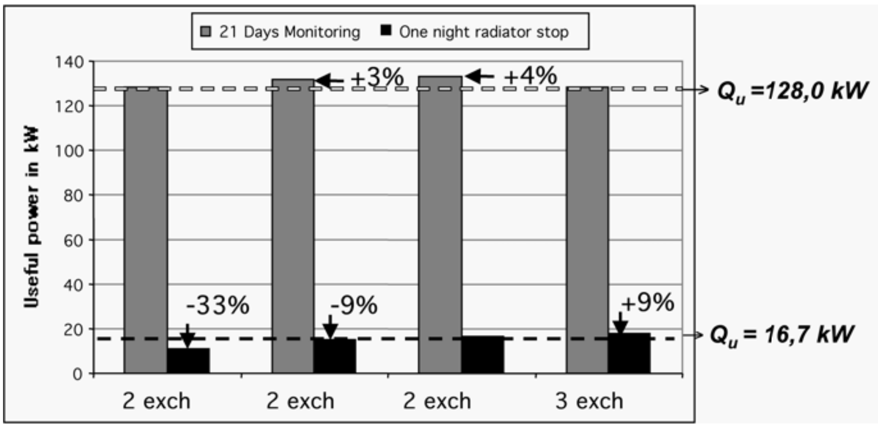

Figure 8: Useful power delivered by the two and three exchangers models:

The two exchangers model is not able to reproduce the mean values recorded both for the 21-days monitoring and for the night without radiator supply: either it reproduces well the day results, or it reproduces well the night results. The three exchangers model offers a better compromise, with better priority to the day results, as they are those involving higher heating powers.

The model of the apartments building heating plant (Figure 5) yields a complete heat balance of the building and of its heating system on a three years period. The resulting heat balance is presented on Figure 9, while the evolution of the indoor temperature and of the rate of 100% nominal flow supplied radiators is given on Figure 10.

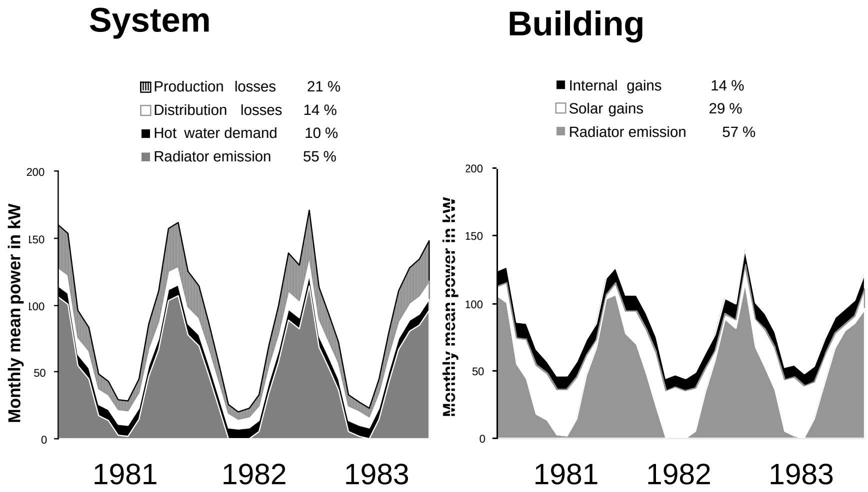

Figure 9: Heat balances of the apartments building and of its heating system.

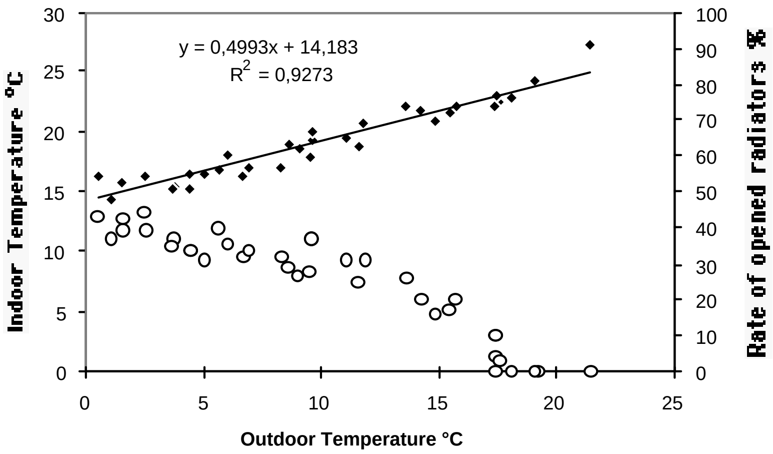

Figure 10: Evolution of the indoor temperature (black symbols) and rate of 100% nominal flow supplied radiators (white symbols)

CONCLUSIONS

As far as building models are concerned, measurements reveal significant overestimations of the calculated heat demand and of the calculated global heat losses (transmission and ventilation). The overestimation of transmission building heat losses can be explained by the overestimation of glasses convection losses, and by the existence of contact resistances between opaque wall layers. Existing simulation models need to be calibrated.

As far as boiler model is concerned, the better response of the three exchangers model is due to the presence of hot spots as the boiler is old.

As far as heating plant is concerned, the heat balance obtained by simulation highlights important production losses, suggesting a renewal of the boiler as energy saving opportunity. Distribution losses could also be reduced in the hot water distribution circuit by improving insulation, by stopping hot water distribution during the night or by decreasing hot water distribution temperature.

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